THE MANUFACTURING RESEARCH
CORPORATION OF ONTARIO

1990-1991 REPORT

CENTRE OF EXCELLENCE SUPPORTED BY
THE ONTARIO TECHNOLOGY FUND

Ontario

MISSION STATEMENT

The Manufacturing Research Corporation of Ontario (MRCO) supports industrial innovation in Ontario by facilitating the timely and effective transfer of technological advances from the research community to the manufacturing sector.

MRCO directly funds and manages fundamental research at Ontario universities. The corporation sponsors research projects which are relevant to industrial needs. MRCO also helps manufacturers find research expertise to develop applied technology solutions to manufacturing problems.

Innovations in advanced technology are required to ensure the future competitiveness of Ontario manufacturers in international markets. By bridging the gap between manufacturers and the research community, MRCO contributes to the development of an innovative, R&D–driven industrial culture in Ontario.

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Front cover:

With the help of MRCO, companies are making impressive advances in manufacturing efficiency.
This precision vertical boring and milling machine is used in metal foundries to dramatically cut production time.

CHAIRMAN'S REPORT

The Manufacturing Research Corporation of Ontario (MRCO), one of seven Centres of Excellence supported by the Ontario Technology Fund, completed its third successful year of operation. There were several changes to MRCO's governing body for the 1990/1991 fiscal year.
Dr. William Lennox completed his term on MRCO's Board of Directors and is succeeded by Dr. David Burns, Dean of Engineering at the University of Waterloo. The Board would like to welcome Dr. Burns and thanks Dr. Lennox for his participation and guidance over the past three years. A complete listing of the Board of Directors is noted at the end of this report.

MRCO's mandate is to administer and monitor manufacturing research projects at Ontario universities, facilitate the transfer of this research to industries within Ontario, and enhance industry-university relations. MRCO, through its involvement with research institutions and manufacturers, develops innovative ways to reduce production costs and in turn, improve the global competitiveness of manufacturers located in Ontario.

One of MRCO's primary objectives, promoting advanced manufacturing research and development projects at Ontario universities, continues to expand. During the past year, the University Research Program consisted of 51 projects at six Ontario universities. The research was directed by 29 principal researchers supported by 48 associate researchers. Funds allocated by MRCO to support this research equated to $5.6 million and supported projects in four theme areas: process, design, automation, and management.

Another major initiative is MRCO's industrial activity, involving over 60 companies in various cost reduction projects. The industrial section of this annual report will provide further detail on MRCO's industrial activities.

One of the primary mechanisms utilized by MRCO to meet its objective of increasing the competitiveness of Ontario-based manufacturing is the use of consortia. Consortia projects varied from "Using Waste Foundry Mold Sands in the Manufacturing of Asphalt" to "Developing a User–Predictive Modelling of Deep Draw Metal Stamping". MRCO encourages and facilitates the bringing together of industrial participants to focus on issues of common concern on behalf of the consortium members by leveraging their access to technology and resources.

MRCO intends to further facilitate the formation of consortia in 1991 in the areas of heat treating processes, computer integrated manufacturing and a project to better understand the interactive human behaviour issues affecting productivity in a manufacturing environment.

One of the conditions of funding for MRCO, as well as all the Centres of Excellence, is that a performance review and evaluation be conducted at the mid–point of the funding cycle. The following excerpts from the 30–Month Review are relevant to the issue:

> *"MRCO has achieved both government's and its own objectives in the short period of time it has been in operation."*

The collective view of the Premier's Council Sub-Committee on the Centres of Excellence and the Chairman of the Review Panel is:

> *"Without question, the Manufacturing Research Corporation of Ontario is fulfilling the objectives of stimulating the production of advanced world-class researchers and encouraging the transfer and diffusion of technology."*

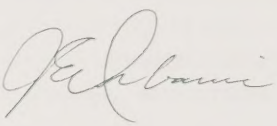
MRCO recognizes the opportunity for continuous improvement and believes that networking between universities will bring added value to the research and development process through improved communications and linkages among individuals with common interests. Accordingly, network-promoting activities such as the annual conference will continue to be an integral part of MRCO's

strategic plan for the upcoming year. Future conferences and symposiums are being planned, and consideration is being given to a potential opportunity for a new mega project requiring cross-discipline collaboration.

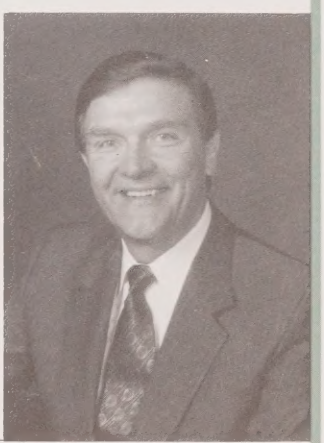
In addition, a key focus of MRCO will be a strengthened communications program designed to create awareness of the organization's goals and objectives. One of the core objectives of expanded communications is to meet with primary and secondary school students to explain the importance of continuing their education, especially in the fields of science and engineering.

MRCO is of the opinion that Ontario's industry requires support through the transfer of the right technology to become and remain competitive in the global economy. The Board of Directors affirms that MRCO performs this function very well, serving to meet the needs of all sectors of the manufacturing community, particularly striving to meet the requirements of the small and medium-size businesses which are the engine of Ontario's economy. The Board is confident that the government will also agree that MRCO's role is vital to Ontario's successful participation in the international marketplace.

The Board of Directors of the Manufacturing Research Corporation of Ontario wishes to thank the Provincial Government for their ongoing support.



J.E. Urbanic
Chairman



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PRESIDENT'S REPORT

The Manufacturing Research Corporation of Ontario has been vigorously pursuing the challenge presented by its mission statement. MRCO is proud to announce that the level of activity in its Industrial Participation Program (IPP) has propelled the company toward becoming a principal technology transfer agent in the province. Concurrently, MRCO continues to successfully achieve its research and development objectives by supporting and managing fundamental research at Ontario universities.

MRCO provides vital support to its growing number of industrial partners by identifying appropriate technology and transferring it into their manufacturing environments, thereby enhancing their operations. Under this Industrial Program umbrella, the transfer process has two main thrusts; namely, the industry-based Consortia Program and the university-based Technology Transfer Program. Both approaches create opportunities for MRCO to employ its expertise in identifying the technology required to fulfil a need and to deliver that technology to Ontario manufacturers.

The Consortia Program enables manufacturers to pool their resources for technical development: common problems are identified and solved. This method produces a significant return on investment for each member as each contribution is leveraged. During the past 18 months, $11 million of industrial technology contracts have been acquired and in many instances have resulted in greatly reduced costs, new or saved business and saved or added jobs.

The Technology Transfer Program allows MRCO to harvest technology as it develops from its industry-targeted university research projects. Early identification of opportunities for industrial involvement is the mandate of MRCO representatives. Industry support of any project is essential because the "reduction-to-practice" phase invariably requires a partnership of both university and industry to successfully conclude the transfer of technology.

MRCO's funding and management of fundamental research at Ontario universities has supported an academic team of 253 researchers at six Ontario universities. Seventy-seven professors (principal investigators and their associates) successfully directed this team with dedication and enthusiasm (Appendix 3). Additionally, MRCO continues to be involved in the co-operative Baden-Wurttemburg Project. This project, jointly funded by the German province of Baden-Wurttemburg and the province of Ontario, seeks to integrate aspects of Computer-Aided Process Planning with Production Planning and Control.

MRCO's activities continued to be supported by dedicated committees. The Senior Advisory Committee (SAC) met eight times last year, providing valuable assistance to MRCO management in the execution of Board directives. The Finance Committee assisted the Board by reviewing and monitoring all quarterly financial statements; the Executive Committee met as necessary at the discretion of the Board to address urgent issues. A list of members of these committees may be found in Appendix 2.

The Scientific and Industrial Advisory Committee (SIAC), composed of 18 internationally recognized experts, conducted the annual peer review of MRCO's research and development portfolio. This unbiased review ensures that MRCO's portfolio of university projects is of high quality and maintains industrial relevance. Additional data on this

committee may be found in Appendix 1. Because of the on-going and successful development of the Industrial Participation Program, head office staff has increased. MRCO is now administered by nine full-time, two contract and two part-time employees.

MRCO's communications program has boosted awareness and acceptance of MRCO's ambitious objectives in both the manufacturing community and research institutions. MRCO employs a multi-media approach including print media, radio and television interviews, educational seminars, trade shows, newsletters, brochures and sales literature. The communications program enjoyed a 100% increase in media exposure during the fiscal year 1990/91. MRCO was featured twice in the Report on Business section of The Globe and Mail and was also highlighted in trade publications across the country.

A significant forum for communicating is MRCO's annual conference. This year, for the first time, industry representatives were invited to participate. The inclusion of industry provided an exciting opportunity for manufacturers to interface with university researchers to uncover areas of mutual interest and discuss reciprocal benefits.

The communications program has significantly raised the company's visibility and will continue to be a cornerstone of its growth.

A number of signs point to a growing value-added effect of the Centre of Excellence Program as seen from MRCO's perspective. After a full three years of operation and the expenditure of $19 million of funding provided by the Government of Ontario, the base statistics show that a significant number of graduate students have been supported and that substantial contributions to scientific literature have been made.

As a point of interest, because of McMaster University's participation in MRCO's program, opportunities there for research in manufacturing have occurred that would otherwise not have existed. MRCO funding made it possible to purchase new capital equipment and to modernize that which already existed, as well as to attract and to educate students whose influence on future development in manufacturing engineering will have long-term, lasting effects. The level of activity in the graduate (mechanical engineering) school has more than doubled and the excellence of the research is becoming known throughout the world.

At most of MRCO's six universities, the infrastructure purchased through the MRCO program may well make it possible for research groups to continue as a local focus of manufacturing research capability long after the mandate of the Centre ceases.

Edward A Dyson

E.A. Dyson
President

INTRODUCTION TO THE INDUSTRIAL PARTICIPATION PROGRAM (IPP)

MRCO's Industrial Participation Program has been developing since late 1988. The goal of the program is to encourage the manufacturing community to continuously improve operations through application of technology, thereby improving their competitive position in the world market place. MRCO achieves this by fostering co-operation between industry and the scientific community.

The IP Program, designed to be self-funding, began with the one-on-one or Direct Manufacturing Program. The Consortia Program has recently emerged as an attractive and more effective method of encouraging industrial involvement.

A third program identified to bring technology into the manufacturing community is the Technology Transfer Program. Tech Transfer is the movement of intellectual property from the University Research Program to the shop floor.

Details of these programs are described in the succeeding pages.

MRCO INDUSTRIAL ACTIVITY THROUGH MARCH 1991

Total Companies	**72**
Total Employees	**201,907**
Total Company Sales	**$54 Billion**
Total MRCO Project Value	**$11.7 Million**

The above statistics indicate the number and size of companies who have signed contracts with MRCO since the inception of the Industrial Participation Program.

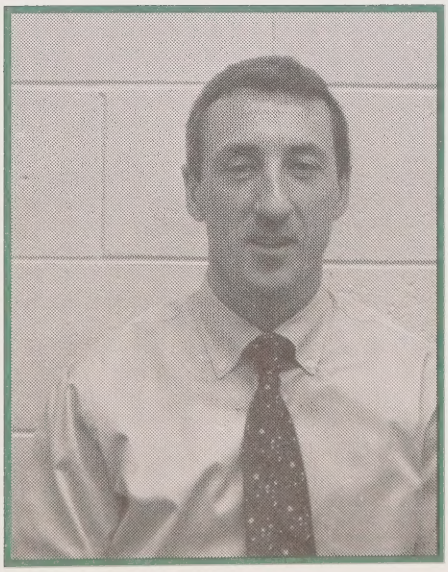
DIRECT MANUFACTURING PROGRAM

MRCO's Direct Manufacturing Program is so named because of the one-on-one contact that MRCO initiates with a single manufacturing company. MRCO representatives first help the manufacturer by thoroughly defining areas needing improvement and then sourcing the appropriate technology expert to provide the solutions. In this approach, each company pays for a customized solution to its unique problem, thereby improving its own performance.

One of the first projects completed in the Direct Manufacturing Program involved the development of a computerized inventory control system for cataloguing and tracking tooling moulds and patterns for **Thompson-Gordon Limited of Burlington, Ontario**. The company lacked the skilled personnel to dedicate to the project. MRCO linked the company with inventory control specialists from a local university, and within five months a new inventory control system was implemented.

In another project, MRCO assembled a research team to help **Kord Products Limited of Burlington, Ontario**, a horticultural packaging manufacturer, redesign both the products and the manufacturing process so that the company could continue to deliver an always improving product at a competitive price.

The foregoing are but two examples of many different projects completed under MRCO's Direct Manufacturing Program.



Peter Francis, Plant Manager
Thompson-Gordon Limited
"MRCO sourced the experts for us and made sure that they knew what we wanted."

CONSORTIA PROGRAM

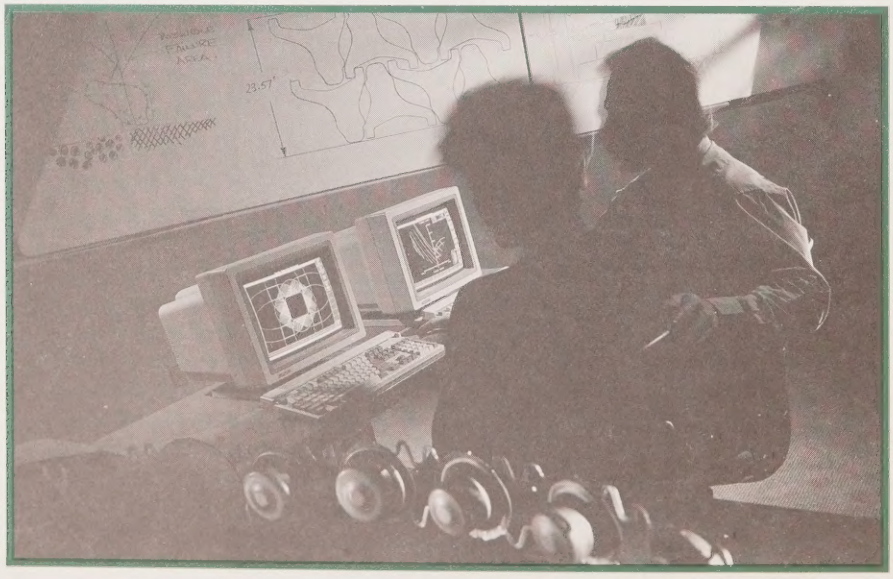
MRCO's Consortia Program provides an excellent opportunity for Ontario manufacturers to pool their financial and technical resources to deliver pre-competitive solutions to industrial problems. This co-operative approach to industrial advancement utilizes the special expertise of each participant to create benefits for all. Furthermore, each consortium is unique in its requirements.

The first consortium developed by MRCO was Formtech Inc.. The 11 consortium members, consisting of metal stampers and steel suppliers, were drawn together to investigate the applications of advanced computer modelling to metal stamping (drawing or forming). The objective was to transform die design and sheet-metal forming from an art practised by experienced operators to a science and engineering-based trade. Ultimately, the goal is to produce highly skilled tradesman in a fraction of the time now required.

An internationally renowned research team has been contracted to develop the solution. With MRCO providing the project management, a series of computer-modelling programs are being developed. These will predict the requirements for acceptable stamping techniques. Several programs in the series have already been delivered to the consortium members. Once completed, these engineering programs will be used at each stage in the development of metal stamping including product design, material selection, process planning, quoting, prototype tooling, tool design and development and process control.

Another industry sector feeling competitive pressure is the foundry industry. Growing environmental concerns coupled with declining productivity have convinced a number of Ontario foundries to come together, under MRCO's guidance, to address issues of mutual concern. MRCO's group, the Canadian Foundry Group Consortium, concentrates on two projects.

The first project uses computers to model the design of sand moulds for foundry castings. Currently, thousands of dollars and hundreds of man-hours are required to design a casting pattern by trial and error, using more art than science. The objective of this project is to create a perfect-first-time casting with predictable finished



Recognizing the critical need for advanced training in Ontario's metal stamping industry, MRCO's Formtech Consortium is developing classrooms and workshops that use computer simulation techniques.

product characteristics. The project will help foundries compete by reducing the costs and time associated with casting design. More details of this project are presented in the Technology Transfer Program section.

The second and very different project is to determine the feasibility of using waste sand from foundry moulds in the manufacture of asphalt for paving. In the past, foundries were permitted to dump thousands of tons of sand, at relatively low cost, in landfill sites. However, over the past few years, disposal costs have increased dramatically due to environmental regulations. An alternative use for waste sand had to be found. An MRCO–commissioned feasibility study convinced asphalt producers in Ontario of the desirability of using such sands. MRCO is now involved in pairing foundries with asphalt producers and other potential users, to facilitate the diversion of a quarter–million tons of waste sand from landfill sites in Ontario.

A further example of MRCO's consortia activity is a productivity improvement project for a major Canadian corporation and a number of its suppliers. In this case, the objective is to reduce costs associated with the process of manufacturing a product by implementing the most appropriate and up–to–date systems in each supplier's plant. These systems include just–in–time, manufacturing resources planning, total quality management and integrated manufacturing systems. Each is being adapted for implementation by the participants.

These are but three examples of successful consortia managed by MRCO; others are operating, and still others are in various stages of development.

The development and on–going management of consortia require dedication, skill and patience; a successful track record indicates that MRCO has mastered these qualities. The specialized management services provided by MRCO include sourcing and contracting for the appropriate research and development services, providing specialized legal and financial services, and assisting in finding alternate sources of funding.

To help protect the environment, the MRCO managed Foundery Consortium is developing value-added ways to use spent foundery sand. Here, premium blending sand is used in the production of asphalt.

TECHNOLOGY TRANSFER PROGRAM

As an introduction to the Technology Transfer Program an overview of MRCO's University Research Program is in order.

MRCO's University Research Program was developed on the premise that long–term benefits would accrue to the industrial sector if respected researchers, working in areas having an impact on manufacturing, were supported. Major products of the University Research Program are of course, graduate students and technical information. The details of the program are listed separately.

Of particular interest is the likelihood that some projects of the University Research Program will yield intellectual property that may be transferable to industry. After all, intellectual capital is one of Ontario's most valuable assets and can be one of its finest competitive weapons in a business environment of intense international competition. Much of this intellectual property is the result of university–based research. Transferring this resource into the manufacturing community is an important part of MRCO's mission. The challenge is to encourage the manufacturing community to view university research and technology innovation as an exciting opportunity for increased growth and wealth for the manufacturers.

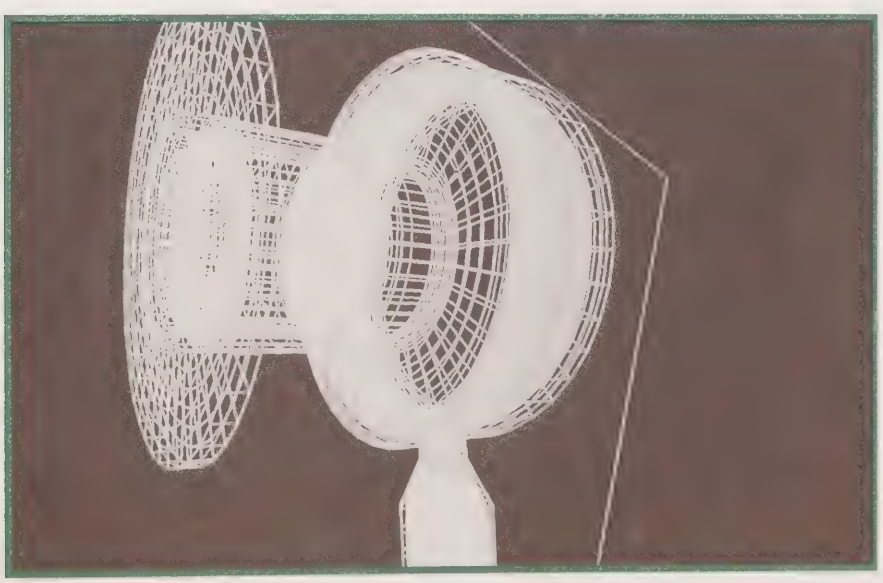
The technology transfer process is complex. It depends on the development of relationships between individuals from different fields. Initially, the technology transfer process is driven by an inventor who is excited with a discovery. This provides the technology push. Ultimately, the momentum shifts to a potential user who anticipates the benefits that the invention represents to the business. This provides the technology pull. The push/pull process is the only way that intellectual property can flow effectively from the invention stage to the final application.

Generally, intellectual property developed in the university cannot be immediately transferred to industry — some development of the invention is required. The user, having recognized that a cost advantage to the company may exist, agrees that the benefits are worth the risk and costs in developing or reducing the technology to commercialization. It must be remembered that technology transfer will not occur without a net benefit to the user.

A good example of the technology transfer process in action is a project under the MRCO "Design" theme, directed by Professor John Goldak at Carleton University. Professor Goldak's work, based on physics and fluid flow, has produced a software capable of simulating the changes, in real time, that occur when molten metal is cast into a sand mould to produce a particular product such as a gear or cam shaft. The computer screen will show how heat is, and is not, removed from the part as the liquid metal cools and changes to a solid. This feature is invaluable to the designer of the mould because, if the cooling is not carefully controlled, there can be gas bubbles or changes in the crystal structure of the metal that cause unacceptable weak spots in the part. Heretofore, a good design was produced after a lengthy trial and error process taking up to two years. Goldak's software has the promise to allow the designer to "see" where design faults are located and to make the necessary alterations immediately. Product development can be reduced to just a few weeks!

Similarly, at the University of Toronto, considerable interest has been generated by another product of MRCO's research program, specifically, technology developed by Professor R. Woodhams to extrude ultra–high molecular weight polyethylene. The process imparts very high tensile strength, equal to that of steel, to the polymeric material. The attraction of an apparently low–cost polyethylene with exceptionally high strength, has obvious appeal. Demonstrations of applications for the technology are currently being pursued with a number of manufacturers.

MRCO will continue to act as a major catalyst, bridging the gap between industry and applied technology. The ever–increasing pace of scientific and technological advancement demands that MRCO continue to assist Ontario manufacturers to improved global competitiveness with leading edge technology.



Finite element mesh of casting for use in heat transfer analysis.

INTRODUCTION TO THE UNIVERSITY RESEARCH PROGRAM

MRCO continues to support research at six Ontario universities. MRCO's strategy has been, and will continue to be, to support the work of Ontario's academic researchers who have achieved recognition as leaders in their fields and whose work clearly has beneficial impact on the manufacturing industry.

During the fiscal year 1990/91, 51 projects were directed by 29 principal investigators and supported by 48 associated researchers. Thirty–one project budgets were allocated as follows:

Carleton University	1
McMaster University	8
Queen's University	1
University of Toronto	9
University of Waterloo	11
University of Western Ontario	1

MRCO's dedication to the development of Ontario's graduate student resource continues to be evident: a total of 160 students received financial support during 1990/91.

It is interesting to observe that concurrent with MRCO's program, both Federal Government and industrial support to MRCO's researchers have increased continuously over the three-year period. Chart 1 shows a two–fold increase in Federal Government support. Industrial support grew from $400,000 to $4.9 million (Chart 2). These charts may be found in Appendix 4.

MRCO's research program is structured under four theme areas: Automation, Design, Management, and Process. The following section provide examples of research projects currently underway in each area.

AUTOMATION

Focus

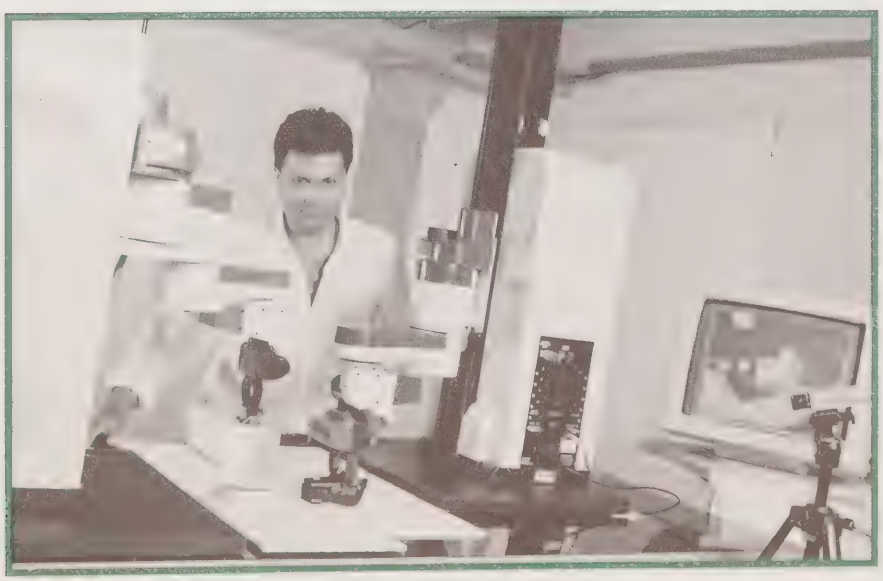
Automation in manufacturing involves product design, process planning, and production. Any activity required to conceive, build and sell a product is ideal for consideration of automation techniques. MRCO's main objective in supporting such research is improved productivity, ultimately resulting in lower costs per unit of production.

Highlights

At the University of Waterloo, an advanced approach to the development of machine intelligence systems is represented by MRCO's project, "Sensor and Knowledge–Based Robotics," directed by Professor Andrew Wong. The achievement of the intelligent system to support flexible manufacturing tasks includes: on–line task planning, visual recognition of the work environment, visual inspection of parts being manufacturing, on–line co–ordination of robots for discrete tasks, on–line control of a robot work station, and autonomous robots in space.

Dr. Wong's Pattern Analysis Machine Intelligence (PAMI) group has developed a vision system with a 3–D scene recognition and interpretation capability, which is essential for the guidance system of an autonomous robot. This system is also capable of relating instructions to the robot for task and trajectory planning, control and task monitoring.

As a direct result of this research, several advanced industrial and space robotic projects in computer vision, modelling and task planning have been supported. Furthermore, several industrial projects are either direct or indirect spin–offs from PAMI's computer–vision technologies. These projects include: image processing and optimal pattern layout of 2–D patterns on hides, real–time monitoring of segmentation of tar sands in a settling vessel, and 3–D inspection of circuit boards.



Two independently controlled robots cooperating in an assembly task.

DESIGN

Focus

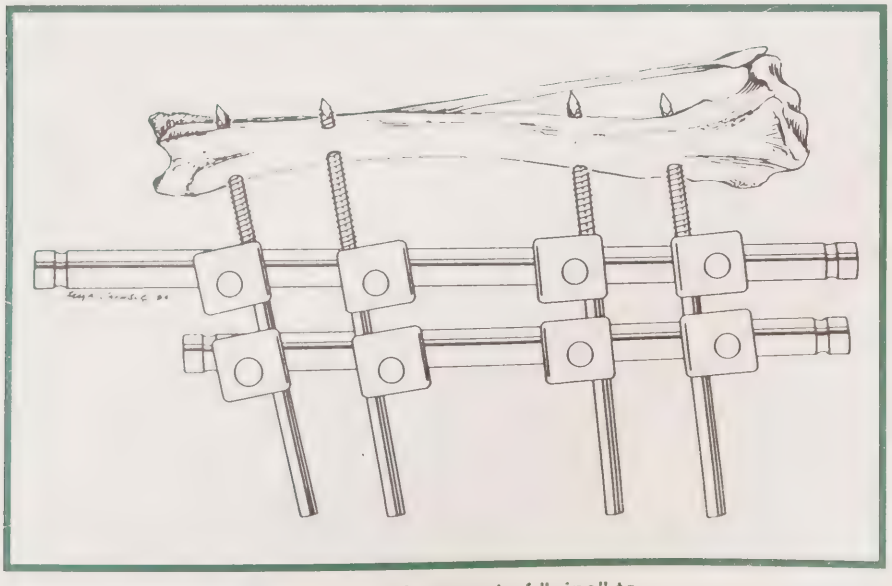
Design in manufacturing involves the integration of analysis software with actual product design. Projects within MRCO's Design group all support design as an integral part of manufacturing. The majority of the projects use software development to resolve design issues such as vibration, stress and systems dynamics.

Highlights

The objective of Dr. Shaker Meguid's project, "Software Optimization and Integration in Computer–Aided Manufacturing Environment," at the University of Toronto, is to develop a mathematical technique capable of simulating the critical stress regions an object experiences during service. The graphic representation displays a finite element mesh of the part or a representative segment. Dr. Meguid's Engineering Mechanics and Design Laboratory undertakes a variety of projects based on the common platform of design for mechanical integrity and reliability. The Laboratory's research work addresses design issues of current industrial concern and provides the foundation for future developments. Typically, the work contains both fundamental and applied components and utilizes advanced theoretical and experimental techniques in the areas of: crack–tip interaction, fatigue fracture and residual stress, hydrogen embrittlement and corrosion, and computer–integrated design of mechanical systems.

Some past successes included: the design of a novel shock absorber for an electrically–powered vehicle, integrated computer–aided design of a variable speed drive for a crude oil pump, and evaluation of optimum drill hole diameter for external fixation devices for the treatment of fractured bone.

Dr. Meguid and his group are now applying their skills to orthopaedic techniques. In particular, he is helping surgeons understand the peculiar properties of bone and how to optimize the placement of pins so as to immobilize a fracture but, at the same time, consider the mechanics and stress that such a procedure imposes.



The optimal placement of "pins" to immobolize a fractured tibia.

Focus

Management in manufacturing relates to making industrial plants more efficient. The scope includes: inventory control, quality control, material flow, plant layout optimization, simulation and scheduling.

Highlights

Quality is now the number one issue in many progressive manufacturing companies. GM and IBM have adopted the concept of total quality management. GM has established a Quality Chair at the University of Waterloo, and one of MRCO's principal investigators, Professor Jeff Wu, occupies that chair. He is actively applying novel statistical methods and creative thinking for manufacturing process and product improvement.

Professor Wu's research has focused on the development and transfer of novel statistical methods to make experiments more economical, efficient and user–friendly. As demonstrated in theoretical studies and in applications to experiments in Ontario industry, the savings in experiment costs can be quite substantial. The efficiency aspect allows more information to be uncovered from the experimental data; more information can lead to a better understanding of the product and process.

Dr. Wu has also developed innovative graphical aids for the planning of experiments which allow unsophisticated shop floor users to carry on experiments without having a statistical background. Some of the research results have been adopted at GM and its suppliers through the partnership program of the Institute for Improvement in Quality and Productivity and the GM of Canada Quality Resource Centre. These results, in the form of case studies, are documented in the reports of the annual GM of Canada Quality Symposium.

Professor Jeff Wu
University of Waterloo

Focus

Processes in manufacturing examine new methods of reducing costs for processing technology in all material areas. The areas can be as diverse as chemicals, plastics, polymers, metal cutting and forming, and welding and assembly.

Highlights

The purpose of Professor M.A. Elbestawi's research, "Limits, Controls and Optimization of Machining Process," being conducted at McMaster University, is to further develop the control of the process of removing metal using sophisticated numerical control machine tools. The end result should provide improvement in machine productivity by reducing the number of defects. A reduction in the cost of machining is also expected. The thrust of the applied research is "intelligent machining" – a monitoring and control strategy that greatly reduces the need for human intervention once the process has started. The machine will sense obstacles, deviation from the planned path, tool wear, poor quality, and other variables, and will make the necessary adjustments automatically or intelligently, to ensure the planned level of quality.

Intelligent machining is one of the most important emerging technologies in recent decades. Significant research efforts and resources are currently being devoted to the realization of intelligent machine tools in the USA, Europe and Japan.

The basis of Dr. Elbestawi's work is the use of "smart" sensors and controls to monitor and direct the key features of the machining task. Monitoring or intelligent sensing require the design and development of advanced sensing techniques; i.e., force, vibration, vision, accoustics. Controllers will be "intelligent" because they will use a combination of real–time expert systems and adaptive control techniques.

Noteworthy accomplishments of Elbestawi's work include: (1) a tool condition monitoring system which anticipates breakage of the tool, excessive wear, and chatter. (The system has a 96% success rate in detecting these conditions for "turning" (lathe) operations); (2) an expert adaptive controller that can improve productivity and maximize machine utilization; (3) realistic process models for dynamic cutting in machining operations- the model includes the effects of process damping on the prediction of chatter.

Intelligent monitoring and control for a computer numerical control (CNC) milling machine.

APPENDIX 1

Scientific and Industrial Advisory Committee Report

The objectives of the MRCO University Research Program include: an increased number of students graduating with advanced degrees, good quality academic publications and the transfer of technological advances – products of the program – into the manufacturing sector.

The Scientific and Industrial Advisory Committee has the annual task of conducting a peer review to assess the quality of the research and development program. Their criteria are: quality of researcher, quality of the project, its progress, its plan, and industrial relevance. In conducting the tasks, the 12 academic and four industrial members of the committee were organized into four teams of three (two academic members and one industrial).

Each member was supplied with comprehensive "annual reports" prepared by each of the Principal Investigators. The report included up-dated resumes, accomplishments and awards, a work plan and budget request for the new year.

All 51 projects that were reviewed by the committee were given satisfactory or greater ratings. As a result, none of the projects were cancelled.

The quality of MRCO's research and development portfolio remains high. This type of external evaluation process may raise issues that are not made obvious by MRCO's daily interaction. The process is also valuable as it leads to the clarification and accomplishments of goals. SIAC involvement simplifies the industry/academic interface, promotes a better understanding of industrial relevance and improves the likelihood of a successful transfer of the technology to an industrial partner.

APPENDIX 2

COMMITTEE MEMBERSHIP
1990 / 91

SENIOR ADVISORY COMMITTEE

Mr. Michael Brothers
Manager of ADC Product Planning
IBM Canada Ltd.

Mr. Peter Hartwell
Manager, Advance Manufacturing
General Motors of Canada Limited

Mr. Mike Moorcroft
Director, Manufacturing Technology
Northern Telecom Canada Limited

Dr. David Dilts
Director
Waterloo Centre for Integrated Manufacturing (WATCIM)

Mr. Edward A. Dyson
President
MRCO

Dr. Ross Judd
Professor of Mechanical Engineering
McMaster University

Dr. Ron Venter
Chairman of Mechanical Engineering
University of Toronto

Mr. Ed Cinits
Director, Technology Transfer
MRCO

Dr. David R. Henderson
Executive Vice President
MRCO

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Dr. Michael Charles
Vice–Dean of Faculty of Applied Science and Engineering
University of Toronto

Mr. Les C. McLean
Vice President of Quality & Technology
Stelco Inc.

Dr. Clare Beingessner
Vice President of Engineering
B & W Heat Treating (1975) Limited

EXECUTIVE COMMITTEE

Mr. John Urbanic (Chairman)
Director, Car & Truck Assembly Operations
General Motors of Canada

Mr. William J. McClean
Vice President of Manufacturing and Development
IBM Canada Limited

Dr. Michael Charles
Vice–Dean of Faculty of Applied Science and Engineering
University of Toronto

APPENDIX 3

MANUFACTURING RESEARCH CORPORATION OF ONTARIO
RESEARCH EXPENDITURES REPORT
Year Ended 31/03/91

University	Researcher	Theme	Expenses	Project Title
1) Western	ElMaraghy, W.	Design	$ 144,611	Modelling/Design of Multibody Machinery Robots.
		Design	$ 41,320	Design Tolerancing.
		TOTAL:	$ 185,931	
2) McMaster	ElMaraghy, H.	Automation	$ 220,024	Intelligent & Flexible Automation.
		Design	$ 197,408	Feature Based Modelling / Design.
		Design	$ 38,246	Design Tolerancing.
	Elbestawi, M.	Automation	$ 69,057	Sensor Ctr. for Indust. Robots.
		Processes	$ 291,763	Limits, Ctrl. & Optimization of Manufacturing Process.
	Kay, A.	Processes	$ 230,581	Development of Steels with Improved Machinability.
	Sowerby, R.	Processes	$ 203,625	Modelling of Metal Deformation Process.
	Dokainish, M.	Design	$ 102,555	Software Optimization of CIM Procedures.
	Newcombe, W.	Design	$ 841	Integration of Design of Jigs & Fixtures into Design/Mfg. Proc.
		TOTAL:	$1,354,100	
3) Queens	Bayoumi, M.	Automation	$ 229,745	Distributed Multisensory Multiprocessor Ctrl. Hierarchy Algorithms.
		TOTAL:	$ 229,745	
4) Carlton	Goldak, J.	Design	$ 215,580	Feature Based Design of Castings.
		TOTAL:	$ 215,580	

APPENDIX 3 cont'd

University	Researcher	Theme	Expenses	Project Title
5) Waterloo	Wong, A.	Automation	$ 358,492	Sensor Knowledge–Based Intelligent Manufacturing.
	Vidyasagar, M.	Automation	$ 128,700	Design/Ctrl. of Lightweight Robots/Off–line Optimal Path Planning.
	Kerr, H. W.	Automation	$ 400	Constrained Robotics Welding
	Wilson, W.	Automation	$ 56,924	Sensor Integration for Direct End-Point Ctrl. of Robot Manipulators.
	Vannelli, A.	Automation	$ 37,131	Production Scheduling/Design for Assembly of Electronic Circuit Boards.
	Ismail, F.	Processes	$ 19,501	Detection of Vibration/Chattering.
	Martin, H.	Processes	$ 1,297	Detection of Vibration/Chattering.
	Kerr, H.W.	Processes	$ 222,191	Welding Automation.
	Sullivan, G.	Processes	$ 250,376	Computer Aided Process Engineering.
	Schey, J.	Processes	$ 122,746	Trobological Aspect of Metal Forming.
	Lawless, J.	Management	$ 52,546	Analysis/Ctrl. of Warranty Claims/Reliability Problems.
	Buzacott, J.	Management	$ 268,911	Planning/Scheduling Under Uncertainty.
	Wu, C.F.J.	Management	$ 66,396	Implementation/Analysis of Statistically Design Experiments in Manufacturing.
	Yovanovich, M.	Design	$ 250,252	Thermo Fluid CAD & Optimization for Integrated Mfg.
	Andrews, G.	Design	$ 76,633	Integration of Solid Modelling Kinetic Dynamic Analysis.
		TOTAL:	$1,912,496	

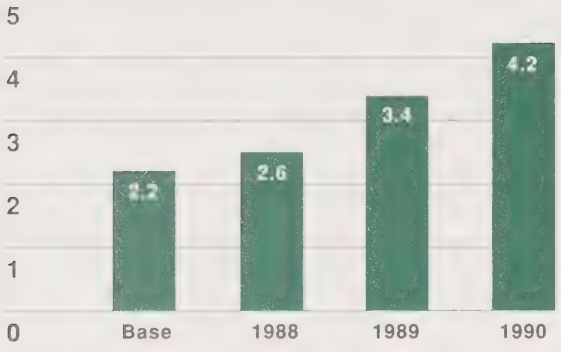
University	Researcher	Theme	Expenses	Project Title
6) Toronto	Davison, E.	Automation	$ 129,032	Dev. of Control Techniques for Robotic Systems/Process Ctrls.
	Smith, K. C.	Automation	$ 184,389	Sensors & Sensor Emphasizing Preconditioning.
	Fenton, R.	Automation	$ 76,806	Robot Structural/Deflection Analysis, Design, Optimization & Performance Evaluation.
	Benhabib, B	Automation	$ 102,212	An Experimental Automatic Workcell, & Analysis/Design of Industrial Robots.
	Goldenberg, A.	Automation	$ 442,513	Uncertain Geometry in Off–line Robot Planning.
	Woodhams, R.	Processes	$ 270,868	Mfg. of Ordered Polymeric Profiles by Extrusion Drawing.
	Sethi, S.	Management	$ 157,324	Statistical Methods for Product Design.
	Turksen, I.	Management	$ 170,036	Knowledge–based Management Systems for Integrated Mfg.
	Meguid, S.A.	Design	$ 200,415	Software Optimizatio Integration in CIM Environment
		TOTAL:	$1,733,595	

APPENDIX 4

Chart 1

Federal Government Support

NSERC & Other - Year-to-Date Comparison

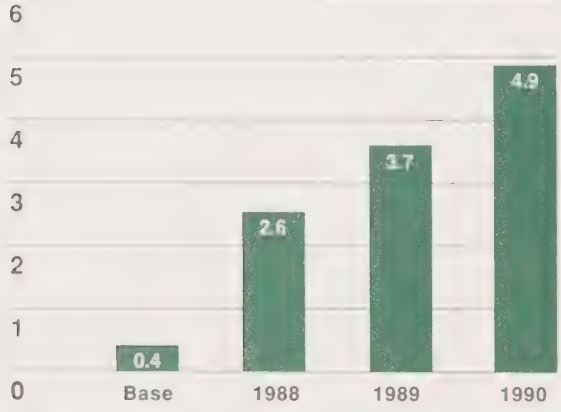


Millions of Dollars

Chart 2

Industry Funding to Researchers

Year-to-Date Comparison



Millions of Dollars

APPENDIX 5

Base Data (Schedule G)

Area	Base	1988	1989	1990 **
Education:				
1. Total number of graduate students registered	107	203	253	320
2. Number of above with Visa	N/A	N/A	N/A	80
3. Number of students* leaving	N/A	N/A	N/A	71
4. Number of students* to industry	22	30	44	65
5. Number of students* to industry in Ontario	N/A	N/A	N/A	55
6. Number of students* to university positions	N/A	N/A	N/A	14
Publications:				
1. Number of referred publications	320	259	317	394
2. Number of patents	12	1	2	10
3. Number of invited papers and lectures	133	147	179	206
4. Number of technology licenses to industry	0	1	3	11
Industry Support:				
1. Industry funding to researchers	418,899	2,578,692	3,369,163	4,884,175
2. Industry funding in-kind to support researchers	N/A	N/A	N/A	582,000
3. In-Kind funding by industry to Centre management	N/A	50,000	130,000	300,000
4. Membership fees to the Centre	N/A	0	0	0
Government Support:				
1. NSERC	2,019,146	2,567,676	3,004,873	2,983,097
2. Other Federal	131,333	70,200	362,200	1,247,232
3. Ontario (not Centres)	172,800	988,598	1,095,623	1,643,896
4. Other Government	246,000	643,960	1,026,000	1,111,500
5. Foundations, etc.	96,666	80,000	127,400	51,900
Communications/Technology Transfer:				
1. Number of person days of company employees attending workshops/seminars	N/A	381	472	788
2. Number companys in a working relationship with Centre investigators:				
a) Chair support	0	2	2	2
b) Research interactions	47	97	128	160
c) Contacts	13	23	33	53
d) Consulting fees	8	14	33	39
e) Grant & Donations	14	12	17	23
Collaboration:				
1. Federal Centres of Excellence	N/A	N/A	N/A	15
2. Other Ontario Centres	N/A	N/A	N/A	7
3. Other Canadian	N/A	N/A	N/A	81
4. Other International	N/A	N/A	N/A	67

* Students with studies beyond the Bachelor's degree
** As of March 31, 1991

APPENDIX 6

FINANCIAL STATEMENTS
March 31, 1991

THE MANUFACTURING RESEARCH
CORPORATION OF ONTARIO

AUDITORS' REPORT

To the Members of the
Manufacturing Research Corporation of Ontario

We have audited the financial position of Manufacturing Research Corporation of Ontario as at March 31, 1991 and the statement of income and expenses and change in fund balance for the year then ended. These financial statements are the responsibility of the company's management. Our responsibility is to express an opinion on these financial statements based on our audit.

We conducted our audit in accordance with generally accepted auditing standards. Those standards require that we plan and perform an audit to obtain reasonable assurance whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation.

In our opinion, these financial statements present fairly, in all material respects, the financial position of the corporation as at March 31, 1991 and the results of its operations and the changes in its financial position for the year then ended in accordance with generally accepted accounting principles.

Ernst & Young

Kitchener, Canada,
June 11, 1991.

Chartered Accountants

Manufacturing Research Corporation of Ontario
(Incorporated under the laws of Ontario)

STATEMENT OF FINANCIAL POSITION

As at March 31

	1991	1990
	$	$
ASSETS		
Cash	6,981	12,908
Funds on deposit (note 3)	450,235	566,851
Accounts receivable	98,610	90,963
Due from University of Waterloo - interest	83,406	9,390
Due from Formtech Inc. (note 4)	-	41,520
Advances to researchers	37,500	102,402
Prepaid rent	1,907	1,907
Fixed assets (note 5)	3,718,239	3,019,502
	4,396,878	3,845,443
LIABILITIES, EQUITY AND FUND BALANCES		
Accounts payable	146,663	238,637
Due to Formtech Inc. (note 4)	220,869	-
Deferred revenue	49,500	-
Equity in fixed assets (note 5)	3,718,239	3,019,502
Fund balance	261,607	587,304
	4,396,878	3,845,443

See accompanying notes

On behalf of the Board:

J.E. Urbanic
Director

E.A. Dyson
Director

STATEMENT OF INCOME, EXPENSES AND CHANGE IN FUND BALANCE

Year ended March 31

	1991 $	1990 $
INCOME		
Government grants (note 2)	6,239,300	6,024,000
Research contracts (note 7)	529,277	364,824
Interest income	187,721	132,987
	6,956,298	6,521,811
EXPENSES		
Salaries and benefits	3,235,112	2,743,942
Overhead	1,754,264	1,529,598
Direct operating	1,586,416	1,169,967
Capital	692,913	1,003,567
	7,268,705	6,447,074
(Decrease) increase in fund balance from operations	(312,407)	74,737
(Decrease) increase in fund balance from Baden-Wurttemberg project (note 8)	(13,290)	16,089
(Decrease) increase in fund balance	(325,697)	90,826
Fund balance, beginning of year	587,304	496,478
Fund balance, end of year	261,607	587,304

See accompanying notes

NOTES TO THE FINANCIAL STATEMENTS

March 31, 1991

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES AND REPORTING PRACTICES

The Manufacturing Research Corporation of Ontario ["the Centre"] was incorporated on December 24, 1987 under the laws of Ontario as a not-for-profit corporation. The aim of the Centre is to foster long-term advanced research in manufacturing by universities and industry, and thus to enhance both knowledge and application of technology in order to help ensure the future research and industrial competitiveness of the Province of Ontario in a global context. This research is performed in a cooperative venture between post-secondary educational institutions and industry. The Centre is managed independently of the universities and industries which have created, and are participating in, the work of the Centre.

The following summarizes the significant policies followed by the Centre:

Fund accounting

The accounts of the Centre have been maintained in accordance with the principles of fund accounting in order that limitations and restrictions placed on the use of available resources may be observed.

Accrual accounting

The accrual basis of accounting is followed whereby research and other expenses are recorded when incurred, and revenues when collected or when collection is virtually certain.

Fixed assets

Equipment purchases are expensed in the period incurred.

The accumulated original cost of fixed assets, less any disposals, is recorded on the statement of financial position; equity in fixed assets is recorded to the extent that asset acquisitions are currently funded or debt incurred to acquire such assets has been retired.

2. FUNDING OF THE CENTRE

The Province of Ontario is committed to make grants to the Centre of not more than $31,000,000 over a period of five years on account of the program. The grants are to be provided quarterly, in accordance with the business plan submitted by the Centre. During the fiscal period ended March 31, 1991 the Centre received $6,239,300.

2. FUNDING OF THE CENTRE CONT'D

Future funding from the Province of Ontario is contingent upon the Centre meeting certain criteria. Funding has been approved as follows:

	$
Received to date	19,566,211
Subsequent funding schedule	
March 31, 1992	6,462,000
December 31, 1992	4,971,789
	11,433,789
	31,000,000

The amount of the unexpended portion of the Provincial grants which may be utilized in any subsequent operating period shall not exceed the following:

End of operating period allocation	% of period
4	5
5	5
6	0

3. FUNDS ON DEPOSIT

Funds on deposit are held by the University of Waterloo on behalf of the Centre. The University of Waterloo pays the Centre interest at the average monthly rate of return earned on the University's short-term investments.

4. MANAGEMENT CONTRACTS

The Centre manages the business affairs of Formtech Inc., an industry consortium formed to conduct research in the field of metal stamping. In return for this service the Centre is paid $100,000 per annum which is reflected in revenue from research contracts. The banking activities of Formtech Inc. are conducted through the Centre which has resulted in a balance payable to Formtech Inc. at the year-end. Formtech Inc. transactions are not otherwise recorded in the Centre's financial statements.

5. FIXED ASSETS

All equipment or other assets purchased with any part of the Provincial grants shall be the property of the Centre. Upon termination of the Centre or, if the agreement with the Government of Ontario is terminated prior to December 31, 1992, the ownership of the assets transfers to the Government of Ontario. Participants in the Centre shall have an option to acquire the assets at fair market value at that time.

6.
CONTRACT RESEARCH - UNIVERSITIES

The Centre subcontracts research performed on its behalf to faculty members of the universities of Toronto, Western, Waterloo, McMaster, Queens and Carleton. Salaries expense represents administrative salaries, reimbursement to participating universities for the cost of incremental personnel directly involved and working in the research programme of the Centre, and the costs to purchase release time from teaching duties in order to free additional time for personnel to dedicate to the programme. Overhead is generally charged at a rate of 65% of salaries and benefits by the participating universities; such charge is meant to recover both the general university costs of the research programme, and the incremental cost of providing general infrastructure support at the academic unit level. Academic units of the universities are required to utilize 24% of the overhead charge as a research grant for the enrichment of the Centre's research programme.

7.
RESEARCH CONTRACTS - INDUSTRY

The Centre enters into research contracts with the corporate sector including both individual companies and industry consortia. The revenues earned from this research are paid directly by industry.

8.
BADEN-WURTTEMBERG PROJECT

The Manufacturing Research Corporation of Ontario entered into an agreement with the Province of Ontario effective January 1, 1990 which states that the Province is to provide additional funding to the Manufacturing Research Corporation of Ontario in the amount of $690,000 over a 3 year period. This funding is to be used for the Computer-Aided Process Planning/Production and Control Integration Project which has as its major objective the improvement in the implementation of Computer Integrated Manufacturing. The research is to be conducted in conjunction with the Fraunhofer Institute for Production Automation of the State of Baden-Wurttemberg, Germany. The agreement between the Fraunhofer Institute for Production Automation and the State of Baden-Wurttemberg is similar to the agreement between the Manufacturing Research Corporation of Ontario and the Province of Ontario and is for the same amount. Technology transfer will take place between the two companies, but no funds will be transferred.

8.
BADEN-WURTTEMBERG PROJECT cont'd

Future funding from the Province of Ontario is contingent upon the Project meeting certain criteria. Funding has been approved as follows:

	$
Received to date	286,165
Subsequent funding schedule	
March 31, 1992	231,335
December 31, 1992	172,500
	403,835
	690,000

	1991 $	1990 $
Income		
Government grants	228,665	57,500
Interest	1,540	-
	230,205	57,500
Expenses		
Salaries and benefits	130,184	24,822
Overhead	86,401	16,134
Direct operating	21,086	455
Capital	5,824	-
	243,495	41,411
(Decrease) increase in fund balance from Baden Wurttemberg Project	(13,290)	16,089

9.
STATEMENT OF CASH FLOWS

A statement of cash flows has not been included in these financial statements as it is not considered to provide additional meaningful disclosure.

THE MANUFACTURING RESEARCH
CORPORATION OF ONTARIO

1075 North Service Road West,
Suite 201,
Oakville, Ontario L6M 2G2